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Full Length Article

Narrow band flame emission from dieseline and diesel spray combustion in a constant volume combustion chamber

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HIGHLIGHTS

- Spray combustion of diesel-gasoline blend was tested in constant volume combustion chamber.
- Multiband flame emission was measured for different ambient conditions.
- Flames of the two fuels become shorter, thinner and stronger with increased ambient oxygen concentration and temperature.
- Experimental observations were analyzed by an empirical model.

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ABSTRACT

In this paper, spray combustion of diesel (No. 2) and diesel-gasoline blend (dieseline: 80% diesel and 20% gasoline by volume) were investigated in an optically accessible constant volume combustion chamber. Effects of ambient conditions on flame emissions were studied. Ambient oxygen concentration was varied from 12% to 21% and three ambient temperatures were selected: 800 K, 1000 K and 1200 K. An intensified CCD camera coupled with bandpass filters was employed to capture the quasi-steady state flame emissions at 430 nm and 470 nm bands. Under non-sooting conditions, the narrow-band flame emissions at 430 nm and 470 nm can be used as indicators of CH^* (methylidyne) and $HCHO^*$ (formaldehyde), respectively. The lift-off length was measured by imaging the OH^* chemiluminescence at 310 nm. Flame emission structure and intensity distribution were compared between dieseline and diesel at wavelength bands. Flame emission images show that both narrow band emissions become shorter, thinner and stronger with higher oxygen concentration and higher ambient temperature for both fuels. Areas of weak intensity are observed at the flame periphery and the upstream for both fuels under all ambient conditions. Average flame emission intensity and area were calculated for 430 nm and 470 nm narrow-band emissions. At a lower ambient temperature the average intensity increases with increasing ambient oxygen concentration. However, at the 1200 K ambient temperature condition, the average intensity is not increasing monotonically for both fuels. For most of the conditions, diesel has a stronger average flame emission intensity than dieseline for the 430 nm band, and similar phenomena can be observed for the 470 nm band with 800 K and 1200 K ambient temperatures. However, for the 1000 K ambient temperature cases, dieseline has stronger average flame emission intensities than diesel for all oxygen concentrations at 470 nm band. Flame emissions for the two bands have a smaller average emission area under higher ambient oxygen concentration and temperature for both fuels, while dieseline has a slightly larger average flame emission area than diesel for most cases. The experimental findings were further analyzed and discussed based on an empirical model of the distributions of air and fuel. Both experiment results and theoretical model show that dieseline has wider 430 nm and 470 nm band emissions than diesel under all conditions.

1. Introduction

Due to more stringent emission regulations on diesel engines, reducing the particulate matter (PM) and oxides of nitrogen

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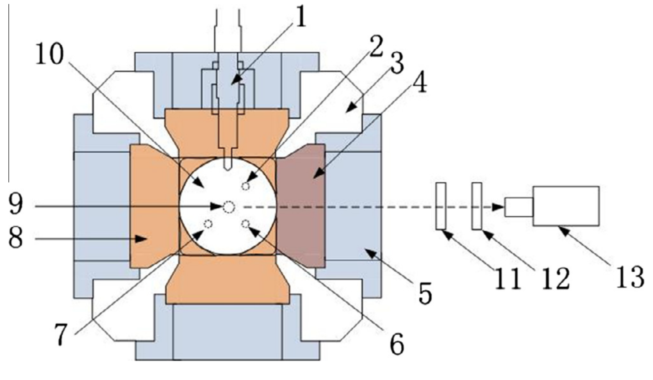

Fig. 1. Experimental system: 1. fuel injector, 2. exhaust line, 3. chamber body, 4. quartz window, 5. plug/window retainer, 6. pressure transducer, 7. intake line, 8. metal plug, 9. spark plug, 10. combustion chamber, 11. natural density filter, 12. band pass filter (310 nm, 430 nm, and 470 nm, 10 nm FWHW), 13. cameras (Andor ICCD camera).

Table 1
Composition of the premixed combustion reactants.

No.	Fuel	Ambient oxygen (%)	C_2H_2 (V%)	O_2/N_2 (V%)	Air (V%)	MW (g/mol)	Density (kg/m^3)
1	Diesel/ dieseline	12	4.81	13.37	81.82	28.85	15.06
2	Diesel/ dieseline	15	4.83	24.19	70.96	28.97	15.04
3	Diesel/ dieseline	18	4.86	35.13	60.01	29.09	15.03
4	Diesel/ dieseline	21	4.89	45.65	49.46	29.21	15.01

(NO_X) emissions of diesel engines becomes more and more challenging. Dec [1] proposed a conceptual model of direct injection (DI) diesel combustion derived based on laser sheet imaging techniques and illustrated the schematic of spray combustion flame with soot formation, soot oxidation and other key features. Higgins and Siebers [2] and Kanda et al. [3] argued that high temperature and low combustion efficiency contribute to the production of PM and NO_X, while too low temperature results in increased emissions of unburned hydrocarbon and carbon monoxide. Thus lowering the temperature to an appropriate level while using a better injection strategy may be a very effective means to reduce overall emissions. Fang et al. [4] investigated low temperature compression ignition (LTCI) combustion by employing multiple injection strategies in an optically accessible small-bore high-speed direct-injection (HSDI) diesel engine, and showed that increasing injection pressure could greatly reduce soot emissions. Lowering injection pressure was helpful for reducing combustion temperature and NOx production. Zheng et al. [5–7] studied the low temperature combustion phenomenon of alternative fuels in a constant volume combustion vessel and a single cylinder diesel engine. The results showed that the fuels with longer ignition delay due to LTC regime produce lower NOx and soot emissions. Jing et al. [8] analyzed the effect of a pilot fuel injection on diesel spray combustion and lowering the soot formation of the main injection.

Experiments were conducted to visualize and further understand the flame development of diesel spray combustion [3,9–13]. Noguchi et al. [14] found that CHO* and HO_2^* were generated before diesel self-ignition, and spray combustion may start at a lower temperature and pressure in transient engines compared with a static conventional diesel combustion environment. For conventional diesel spray combustion, OH, CH and HCHO radicals can be used to identify active combustion regions of the flame [15]. Dec and Espey [16] showed that the chemiluminescence during diesel auto-ignition has a broad maximum near 430 nm and 470 nm, and appears to result primarily from CH and formaldehyde (HCHO) emissions. These are typical emissions from the cool-chemistry reactions of cool-flame. OH* chemiluminescence is regarded as an indicator for high-temperature reactions and is observed when high temperature heat release begins, which has the strongest emission around 310 nm. Additionally, the presence of OH radicals could be a reason for PM reduction during the HCCI combustion process [16,17]. Higgins and Siebers [2] used OH* chemiluminescence to estimate the lift-off length under quiescent conditions. They found that the lift-off length decreases with increasing ambient gas temperature or density, and increases with increasing injection pressure or orifice diameter.

Table 2
Specifications of the common rail injection system.

Injector control unit	Solenoid
Injector pressure (MPa)	100
Nozzle type	Mini sac
Number of orifice	1
Orifice diameter (mm)	0.150
Injector duration (ms)	4

Furthermore, non-traditional fuels continue to draw much attention, and investigation of combustion characteristics of these fuels or their blends are required before they can be commercially used in diesel engines. Jing et al. [18] studied the spray combustion of biomass derived renewable fuels in a constant volume chamber under different ambient conditions, and found that low ambient temperature with moderate O_2 concentration benefits biomass-based biofuel more than diesel by reducing the formation of soot without increasing the soot temperature significantly. Gasoline/diesel blends (dieseline) have also been studied to some extent. Rezaei et al. [19] determined that the gasoline blending ratio has an important impact on the combustion phase control. Utilization of higher diesel fractions may advance the combustion phase, providing a wider range of ignition timing. Anitescu et al. [20] compared the volatility of automotive gasoline-diesel blends and concluded that the resistance to auto-ignition of a low cetane number (CN) fuel can provide sufficient ignition delay for air-fuel mixing, while a faster vaporization can increase the mixing rate. Al-Abdullah et al. [21] measured the flash points of different gasoline/diesel blends and proposed that blends with gasoline concentrations greater than 50% by volume should be safe to use in vehicles because of its similar flash point to pure gasoline. Ma et al. [22] discussed the spray characteristics of dieseline with different temperatures and back pressures and showed that the liquid phase areas and liquid core length are relatively stable, and a higher temperature or a higher gasoline percentage both can advance the turning point time to the stable value. Ji et al. [23] studied the initial temperature effect on flame spread characteristics of dieseline and argued that the dieseline has higher mean spread velocity of the main flame with higher initial temperature than pure diesel.

Multiple combustion modes and alternative injection strategies with dieseline have also been previously explored. Turner et al. [24] showed that dieseline offers some benefits to the expansion of the operating window and hydrocarbon emissions reduction in HCCI engines, including extended low misfire limit, increased engine stability and reduced peak cylinder pressures. Zhang et al. [25] found that the total particle number concentration of dieseline is reduced by up to 50% and 90% and count median diameter (CMD) is reduced by 25% and 75% than pure diesel at medium and low loads respectively in a CI engine. The smoke and NO_x emissions can be reduced by more than 95% simultaneously with dieseline